

FORM PTO-1590 (Modified)
(REV. 10-95)

U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE

ATTORNEY'S DOCKET NUMBER

TRANSMITTAL LETTER TO THE UNITED STATES
DESIGNATED/ELECTED OFFICE (DO/EO/US)
CONCERNING A FILING UNDER 35 U.S.C. 371

2867-0134-2 PCT

U.S. APPLICATION NO. (IF KNOWN, SEE 37 CFR

09/147230

INTERNATIONAL APPLICATION NO.

PCT/SE98/00353

INTERNATIONAL FILING DATE

27 FEBRUARY 1998

PRIORITY DATE CLAIMED

3 MARCH 1997 (earliest)

TITLE OF INVENTION

IMPROVEMENTS IN, OR RELATING TO SYNCHRONISATION

APPLICANT(S) FOR DO/EO/US

Lennart OLSSON et al

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☒ This is an express request to begin national examination procedures (35 U.S.C. 371(f)) at any time rather than delay examination until the expiration of the applicable time limit set in 35 U.S.C. 371(b) and PCT Articles 22 and 39(1).
4. ☐ A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.
5. ☒ A copy of the International Application as filed (35 U.S.C. 371 (c) (2))
 - a. ☐ is transmitted herewith (required only if not transmitted by the International Bureau).
 - b. ☒ has been transmitted by the International Bureau.
 - c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US).
6. ☐ A translation of the International Application into English (35 U.S.C. 371(c)(2)).
7. ☒ A copy of the International Search Report (PCT/ISA/210).
8. ☒ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371 (c)(3))
 - a. ☐ are transmitted herewith (required only if not transmitted by the International Bureau).
 - b. ☐ have been transmitted by the International Bureau.
 - c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
 - d. ☒ have not been made and will not be made.
9. ☐ A translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
10. ☐ An oath or declaration of the inventor(s) (35 U.S.C. 371 (c)(4)).
11. ☐ A copy of the International Preliminary Examination Report (PCT/IPEA/409).
12. ☐ A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371 (c)(5)).

Items 13 to 18 below concern document(s) or information included:

13. ☒ An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
14. ☐ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
15. ☒ A **FIRST** preliminary amendment.
A **SECOND** or **SUBSEQUENT** preliminary amendment.
16. ☐ A substitute specification.
17. ☐ A change of power of attorney and/or address letter.
18. ☐ Certificate of Mailing by Express Mail
19. ☒ Other items or information:

Notice of Priority

Request for Consideration of Documents Cited in International Search Report

Statement of Relevancy

PTO-1449

Cited References (3)

U.S. APPLICATION NO. (IF KNOWN, SEE 37 CFR	INTERNATIONAL APPLICATION NO. PCT/SE98/00353	ATTORNEY'S DOCKET NUMBER 2867-0134-2 PCT
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20. The following fees are submitted:

BASIC NATIONAL FEE (37 CFR 1.492 (a) (1) - (5)) :

<input type="checkbox"/> Search Report has been prepared by the EPO or JPO	\$930.00
<input type="checkbox"/> International preliminary examination fee paid to USPTO (37 CFR 1.482)	\$720.00
<input type="checkbox"/> No international preliminary examination fee paid to USPTO (37 CFR 1.482) but international search fee paid to USPTO (37 CFR 1.445(a)(2))	\$790.00
<input checked="" type="checkbox"/> Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO	\$1,070.00
<input type="checkbox"/> International preliminary examination fee paid to USPTO (37 CFR 1.482) and all claims satisfied provisions of PCT Article 33(2)-(4)	\$98.00

ENTER APPROPRIATE BASIC FEE AMOUNT =

Surcharge of **\$130.00** for furnishing the oath or declaration later than ☐ 20 ☒ 30 months from the earliest claimed priority date (37 CFR 1.492 (e)).

CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE	
Total claims	29 - 20 =	9	x \$22.00	\$198.00
Independent claims	4 - 3 =	1	x \$82.00	\$82.00
Multiple Dependent Claims (check if applicable) <input type="checkbox"/>				\$0.00
TOTAL OF ABOVE CALCULATIONS =				\$1,480.00
Reduction of 1/2 for filing by small entity, if applicable. Verified Small Entity Statement must also be filed (Note 37 CFR 1.9, 1.27, 1.28) (check if applicable) <input type="checkbox"/>				\$0.00
SUBTOTAL =				\$1,480.00
Processing fee of \$130.00 for furnishing the English translation later than <input type="checkbox"/> 20 <input type="checkbox"/> 30 months from the earliest claimed priority date (37 CFR 1.492 (f)).				\$0.00
TOTAL NATIONAL FEE =				\$1,480.00
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31) (check if applicable) <input type="checkbox"/>				\$0.00
TOTAL FEES ENCLOSED =				\$1,480.00

Amount to be refunded	\$
charged	\$

CALCULATIONS PTO USE ONLY

☒ A check in the amount of **\$1,480.00** to cover the above fees is enclosed.

☐ Please charge my Deposit Account No. _____ in the amount of _____ to cover the above fees.
A duplicate copy of this sheet is enclosed.

☒ The Commissioner is hereby authorized to charge any fees which may be required, or credit any overpayment to Deposit Account No. **15-3000** A duplicate copy of this sheet is enclosed.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

SEND ALL CORRESPONDENCE TO:

OBLON, SPIVAK, McCLELLAND, MAIER & NEUSTADT, P.C.
 1755 Jefferson Davis Highway, Fourth Floor
 Crystal Square Five
 Arlington, Virginia 22202
 703-413-3000

William E. Beaumont

Registration Number 30,996

SIGNATURE

Marvin J. Spivak

NAME

24,913

REGISTRATION NUMBER

November 3, 1998

DATE

09/147230
405 Rec'd PCT/PTO 03 NOV 1998

IN THE UNITED STATES PATENT & TRADEMARK OFFICE

IN RE APPLICATION OF: :

Lennart OLSSON et al :

SERIAL NO: NEW U.S. PCT APPLN. : ATTN: APPLICATION DIVISION
BASED ON PCT/SE98/00353

FILED: HEREWITH :

FOR: IMPROVEMENTS IN, OR RELATING
TO SYNCHRONISATION

PRELIMINARY AMENDMENT

ASSISTANT COMMISSIONER FOR PATENTS
WASHINGTON, D.C. 20231

SIR:

Preliminary to any action on the merits, please amend the above-identified application
as follows:

IN THE SPECIFICATION

Page 1, between lines 1 and 2 insert:

--BACKGROUND OF THE INVENTION

Field of the Invention--:

between lines 6 and 7, insert --Discussion of the Background--.

Page 4, between lines 9 and 10, center and insert --SUMMARY OF THE
INVENTION--.

Page 9, between lines 2 and 3, center and insert --BRIEF DESCRIPTION OF THE
DRAWINGS--;

between lines 8 and 9, center and insert --DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS--.

IN THE CLAIMS

Claim 6, line 1, delete "either", same line delete "or claim 5,".

Claim 10, line 1. change "any of claims 7 to 9" to --claim 7--.

Claim 11, line 1, change "any of claims 7 to 9" to --claim 7--.

Claim 12, line 1, change "any previous claim" to --claim 1--.

Claim 14, line 1, change "any of claims" to --claim 1--;

line 4, delete in its entirety.

Claim 20, line 1, delete "either", same line delete "or claim 19,".

Claim 24, line 1, change "any of claims 21 to 23" to --claim 21--.

Claim 25, line 1, change "any of claims 21 to 23" to --claim 21--.

Claim 26, line 1, change "any of claims 15 to 25" to --claim 15--.

Claim 28, lines 2 and 3 delete in their entirety and insert -- claimed in claim 1.

Claim 29, lines 2 and 3 delete in their entirety and insert -- claimed in claim 1.

IN THE ABSTRACT OF THE DISCLOSURE

Please rewrite the Abstract as follows:

--A multi-carrier system of the OFDM type, having an adaptive channel equalizer operating in the frequency domain. The internal parameters of the equalizer contain, in addition to information about the characteristics of the channel, information which can be interpreted as the time deviation between the sampling clocks of the transmitter and the receiver. This information is used to control the sampling clock of the receiver in a more

robust way then in the prior art. The system can be used in ADSL and BDSL modems which can be used to give broad band access over copper networks. It is also relevant to broadband transmission in mobile and semi-mobile systems for transmission over radio channels.--

REMARKS

Favorable consideration of this application, as presently amended, is respectfully requested.

By way of the present Preliminary Amendment. Applicants have amended the application to place it in better form for examination. Accordingly, headings have been added to the various sections of the specification. Multiple dependencies have been removed from the claims and the abstract has been rewritten in standard U.S. format. No new matter has been entered by way of this amendment.

In view of the above, Applicants submit that the application is now in condition for examination. Accordingly an early and favorable action is respectfully requested.

Respectfully submitted,

OBLON, SPIVAK, McCLELLAND,
MAIER & NEUSTADT. P.C.



Gregory J. Maier
Attorney of Record
Registration No. 25,599
Robert F. Gnuse
Registration No. 27,295

Crystal Square Five - Fourth Floor
1755 Jefferson Davis Highway
Arlington, VA 22202
(703) 413-3000
Fax #: (703) 413-2220

William E. Beaumont
Registration Number 30,996

IMPROVEMENTS IN, OR RELATING TO SYNCHRONISATION

The present invention relates to an OFDM transmission system, an OFDM receiver, OFDM modems including ADSL modems and VDSL modems, and methods of synchronising an OFDM receiver with an incoming multi-carrier signal, in particular, the present invention relates to sampling clock oscillator control for an OFDM system.

In this specification the term OFDM (Orthogonal Frequency Division Multiplex) type is intended to include DMT (Discrete Multi-Tone).

The demand for provision of multi-media and other broad bandwidth services over telecommunications networks has created a need to transmit high bit rate traffic over copper pairs. This requirement has led to the development of a number of different transmission schemes, such as, ADSL (Asynchronous Digital Subscriber Line) and VDSL (Very high bit-rate Digital Subscriber Lines). One of the more likely modulation systems for all these transmission schemes is a line code known as DMT (discrete multi-tone), which bears a strong resemblance to orthogonal frequency division multiplex, and is a spread spectrum transmission technique.

In discrete multi-tone transmission, the available bandwidth is divided into a plurality of sub-channels each with a small bandwidth, 4kHz perhaps. Traffic is allocated to the different sub-channels in dependence on noise power and transmission loss in each sub-channel. Each channel carries multi-level pulses capable of representing up to 11 data bits. Poor quality channels carry fewer bits, or may be completely shut down.

Because inter pair interference in copper pair cables is higher where data is transmitted in both directions, i.e. symmetric duplex, a number of transmission schemes have proposed the use of asymmetric schemes in which high data rates are transmitted in one direction only. Such schemes meet many of the demands for high bandwidth services, such as, video-on-demand.

VDSL technology resembles ADSL to a large degree, although ADSL must cater for much larger dynamic ranges and is considerably more complex as a result. VDSL is lower in cost and lower in power, and premises VDSL units need to implement a physical layer media access control for multiplexing upstream data.

Four line codes have been proposed for VDSL:

- CAP; Carrierless AM/PM, a version of suppressed carrier QAM, for passive NT configurations, CAP would use QPSK upstream and a type of TDMA for multiplexing (although CAP does not preclude an FDM approach to upstream multiplexing);
- DMT; Discrete Multi-Tone, a multi-carrier system using Discrete Fourier Transforms to create and demodulate individual carriers, for passive NT configurations; DMT would use FDM for upstream multiplexing (although DMT does not preclude a TDMA multiplexing strategy);
- DWTM; Discrete Wavelet Multi-Tone, a multi-carrier system using Wavelet Transforms to create and demodulate individual carriers, DWTM also uses FDM for upstream multiplexing, but also allows TDMA; and
- SLC; Simple Line Code, a version of four-level baseband signalling that filters the base band and restores it at the receiver, for passive NT configurations; SLC would most likely use TDMA for upstream multiplexing, although FDM is possible.

Early versions of VDSL will use frequency division multiplexing to separate downstream from upstream channels and both of them from POTS and ISDN. Echo cancellation may be required for later generation systems featuring symmetric data rates. A rather substantial distance, in frequency, will be maintained between the lowest data channel and POTS to enable very simple and cost effective POTS splitters. Normal practice would locate the downstream

channel above the upstream channel. However, the DAVIC specification reverses this order to enable premises distribution of VDSL signals over coaxial cable systems.

In a multi-carrier system, such as a DMT system, a receiver must be able to recover a sampling clock that is very accurately synchronized to a transmitter sampling clock. A known method, for achieving synchronization, uses a reserved carrier, the pilot carrier, which is transmitted with a fixed phase. The receiver sampling clock is then phase locked to the pilot carrier. Frame timing must also be recovered. In existing systems this has been achieved by using a correlation technique operating in the time domain.

With OFDM systems the frequency domain data is the Fourier transform of the received time domain OFDM frames. The time domain frames must be sampled, at the receiver, in synchronism with the transmitter, so that each received frame contains data from only a single transmitted frame. It is vital for this synchronism to be maintained in order to maintain the orthogonality of the frames.

A typical multi-carrier system, of the OFDM type, which uses a cyclic prefix, permits orthogonality to be maintained when there is a small deviation from exact frame synchronisation. Because the signalling interval includes both an entire frame and the cyclic prefix, which is a repetition of part of the frame, a frame sampled within the signalling interval will contain data from only one frame. Since the signalling interval is greater than the frame period, this gives some leeway in frame alignment.

In a multi-carrier system of the OFDM type, the control of the receiver sampling clock is critical for achieving an optimal utilization of the channel capacity. The present invention takes the data needed for this control function from the received signal in a novel manner, in particular, the present invention uses adaptive equalizer parameters for sampling clock oscillator control.

In a multi-carrier system of the OFDM type, an adaptive channel equalizer, operating in the frequency domain, is often used. The internal parameters in such

an equalizer contain, in addition to information about the characteristics of the channel, information which can be interpreted as the time deviation between the sampling clocks of the transmitter and the receiver. The present invention utilizes this information to control the sampling clock of the receiver in a more robust way than has previously been possible with known techniques.

Known techniques for achieving frame synchronisation do not operate entirely in the frequency domain. A technique for frame synchronisation in which only frequency domain data is employed, is described in our co-pending patent application Kgp 74/97.

The present invention is particularly suitable for use in ADSL and VDSL modems which can be used to give broadband access over copper networks with relatively stationary channels. The invention is, however, of general application and also of relevance to broadband transmission in mobile and semi-mobile systems for transmission over the radio channels.

The present invention provides an extremely robust estimation of the time deviation between the sampling clocks of the transmitter and the receiver and can handle deviations of several periods, which implies that symbol limits are also guided to the right location. The robustness is achieved by using all active carriers in the estimation.

According to a first aspect of the present invention, there is provided a receiver, for use in an OFDM type transmission system, in which data is transmitted in frames, each frame having a cyclic prefix which is a repetition of part of said frame, characterised in that control means are provided which control a sampling oscillator, and in that said control means include estimation means for estimating timing deviations of said sampling clock, said estimation means operating entirely on frequency domain input data.

According to a second aspect of the present invention, there is provided a receiver, for use in an OFDM type transmission system, in which data is transmitted in frames, each frame having a cyclic prefix which is a repetition of part

of said frame, and in which said receiver has an adaptive equaliser having an equaliser inverse channel model, characterised in that separation means are provided for separating said equaliser inverse channel model into a first and a second part, said first part being independent of sample timing and said second part being dependent on sample timing and in that control means are provided which control a sampling oscillator in dependence on said second part.

Said control means may include estimation means for estimating timing deviations of said sampling clock, said estimation means operating entirely on frequency domain input data.

Said estimation means may estimate an approximation of a linear portion of an argument function produced by timing deviations of said sampling oscillator.

Said estimation means may be adapted to find a linear part of said argument function by taking an average slope of said argument function.

Said approximation of a linear portion of an argument function may be used as a feedback control signal for said sampling clock.

Said approximation of a linear portion of an argument function may have a slope which converges to zero as a control loop, for said sampling clock, settles.

Those parts of said equaliser inverse channel model, other than said linear portion of said argument function, may be controlled by said equaliser, which continuously adapts to variations in sampling timing.

Said equaliser and said control means may each use well defined and different portions of said equaliser inverse channel model to achieve an output frequency domain signal with zero phase deviation relative to a transmitted signal.

Said slope of said argument function, α_k , may be estimated from the equation

$$\alpha_k = \frac{1}{N} \sum_n \angle \frac{X_{n,k}}{n}$$

where N is the number of active carriers and $X_{n,k}$ is the unwrapped argument function for the nth active carrier in the kth frame.

Said slope of said argument function, α_k , may be estimated from the equation

$$\alpha_k = \frac{2}{n_2 - n_0} \left[\sum_{n=n_1+1}^{n_2} \angle X_{n,k} - \sum_{n=n_0}^{n_1} \angle X_{n,k} \right]$$

where N is the number of active carriers, $X_{n,k}$ is the unwrapped argument function for the nth active carrier in the kth frame, indices n_0 and n_2 are the lower and upper limits respectively of the band and index n_1 divides the band into two equal parts.

On start up, frame timing may be adjusted until received frames are sampled inside a signal interval.

Means may be provided, responsive to a feed back control for said sampling oscillator, to adjust said frame timing so that frame synchronization is maintained.

According to a third aspect of the present invention, there is an OFDM type transmission system in which data is transmitted in frames, each frame having a cyclic prefix which is a repetition of part of said frame, characterised in that said system includes a receiver as defined in any preceding paragraph.

According to a fourth aspect of the present invention, there is provided, in an OFDM type system in which data is transmitted in frames, each frame having a cyclic prefix which is a repetition of part of said frame, a method of synchronising a receiver sampling oscillator with a transmitter sampling oscillator, characterised

by controlling said sampling oscillator with a feedback signal representing an estimation of timing deviations of said sampling clock, said estimation signal derived directly from domain input data.

According to a fifth aspect of the present invention, there is provided, an OFDM type system in which data is transmitted in frames, each frame having a cyclic prefix which is a repetition of part of said frame, and in which said receiver has an adaptive equaliser having an equaliser inverse channel model, a method of synchronising a receiver sampling oscillator with a transmitter sampling oscillator, characterised by separating said equaliser inverse channel model into a first and a second part, said first part being independent of sample timing and said second part being dependent on sample timing and controlling a sampling oscillator in dependence on said second part.

Timing deviations of said sampling clock may be estimated entirely from frequency domain input data.

An approximation of a linear portion of an argument function produced by timing deviations of said sampling oscillator may be estimated.

A linear part of said argument function may be found by taking an average slope of said argument function.

Said approximation of a linear portion of an argument function may be used as a feedback control signal for said sampling clock.

Said approximation of a linear portion of an argument function may have a slope which converges to zero as a control loop, for said sampling clock, settles.

Those parts of said equaliser inverse channel model, other than said linear portion of said argument function, may be controlled with said equaliser, which continuously adapts to variations in sampling timing.

Said equaliser and said control means may each use well defined and

different portions of said equaliser inverse channel model to achieve an output frequency domain signal with zero phase deviation relative to a transmitted signal.

Said slope of said argument function, α_k , may be estimated from the equation

$$\alpha_k = \frac{1}{N} \sum_n \angle \frac{X_{n,k}}{n}$$

where N is the number of active carriers and $X_{n,k}$ is the unwrapped argument function for the nth active carrier in the kth frame.

Said slope of said argument function, α_k , may be estimated from the equation

$$\alpha_k = \frac{2}{n_2 - n_0} \left[\sum_{n=n_1+1}^{n_2} \angle X_{n,k} - \sum_{n=n_0}^{n_1} \angle X_{n,k} \right]$$

where N is the number of active carriers, $X_{n,k}$ is the unwrapped argument function for the nth active carrier in the kth frame, indices n_0 and n_2 are the lower and upper limits respectively of the band and index n_1 divides the band into two equal parts.

Frame timing, on start up, may be adjusted until received frames are sampled inside a signal interval.

Said frame timing may be adjusted in accordance with a feed back signal for said sampling oscillator, so that frame synchronization is maintained.

According to a sixth fifth aspect of the present invention, there is provided an ADSL modem characterised in that said modem has a receiver as defined above, or operates a method of synchronisation as defined above.

According to a sixth aspect of the present invention, there is provided a

VDSL modem characterised in that said modem has a receiver as defined above, or operates a method of synchronisation as defined above.

Embodiments of the invention will now be described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 illustrates, in functional form, an equaliser and sampling control unit in which the present invention can be implemented.

Figure 2 illustrates the time domain data format of an OFDM signal used with the present invention.

The synchronisation process of the present invention is illustrated in a functional form in Figure 1. Incoming frequency domain data is passed via an equaliser to a detector/quantizer and thence to a symbol decoder. The operation of the remaining blocks shown in Figure 1, namely the equalisation parameter updating algorithm, the sampling clock control algorithm and the frame timing algorithm are explained in the following description. It is, however, worth noting at this point that:

- the equalisation parameter updating algorithm takes inputs from the raw frequency domain input data, X, the output of the equaliser, U, and the output of the detector/quantizer, Y;
- the sampling clock control algorithm receives an input from the equalisation parameter updating algorithm, as does the equaliser, and
- the frame timing algorithm accepts an input from the raw frequency domain input data.

The frequency-domain data comprises the received time-domain OFDM frames after Fourier transformation. The time-domain frames must be sampled in synchronism with the transmitter so that each received frame contains data from

only one transmitted frame. This is important in order to maintain the orthogonality of the frames.

Figure 2 shows the time-domain format for the transmission of OFDM frames used with the present invention.

5 The signalling interval contains a cyclic prefix and a frame. The cyclic prefix is a copy of the last part of the frame. This means that a frame sampled anywhere inside the signalling interval will contain data from one transmitted frame only. A deviation from the exact frame timing will, therefore, lead to a cyclic permutation of the frame. The orthogonality will, however, be maintained.

10 As previously stated, the present invention relates to, among other things, a method for sampling clock oscillator control in a system of the OFDM type, which is based on adaptive equalizer information. The method of the present invention assumes that the linear part of the equalizer parameter argument vector is related to the frame timing deviation. The estimation of the frame timing deviation is performed entirely in the frequency domain and the deviation estimate is used as a feed-back control signal for the sampling clock Oscillator.

15 A training procedure must be used at start-up. The frame timing is adjusted until the received frames are sampled inside the signalling interval, see our co-pending patent application Kgp 74/97. The sampling clock frequency must also be adjusted so that it is sufficiently close to the transmitter clock frequency to enable the equalizer to follow changes in the timing deviation.

20 Frame start pulses are generated by counting sampling clock intervals. Therefore, after the initial setting of the frame start pulse timing during the training procedure, the timing of the frame start pulse will need to be modified by the feed-back control of the sampling clock oscillator, in order to maintain frame synchronisation.

25 After the training procedure, the equalizer parameters EQ will represent the complex frequency domain inverse of the channel. If there is a deviation from the

correct timing of the time domain sampling of the frames, there will also be a linear part of the equalizer inverse channel model argument function. The adaptive equaliser constructs a model of the transmission channel and applies an inverse of this model to incoming signals - the equaliser inverse channel model.

The exact linear argument function, produced by the timing deviation, is not available, but an approximation can be estimated using the equalizer parameters. The argument function of the equalizer parameters is generally non-linear, but a linear part can be found by taking the average slope of the argument function. This slope estimate is used as a feed-back signal to control the sampling clock oscillator frequency. The slope will converge towards zero as the sampling clock control loop settles.

The rest of the equaliser inverse channel model is taken care of by the equalizer, which continuously adapts to variations in the sample timing.

The advantage of this technique is that the equalizer and the sampling control use well defined separate parts of the equaliser inverse channel model to achieve an output frequency domain signal with zero phase deviation relative to the transmitted signal.

The argument function of the equalizer parameters is the vector of arguments of the individual complex elements. The argument of a complex number is the inverse tangent of the imaginary part divided by the real part. A problem associated with this calculation is that the inverse tangent function is periodic, with a period 2π radians. In this application it is necessary to handle larger arguments than π radians, which is the range of the inverse tangent function. An assumption used here is that the difference in argument between adjacent parameters is smaller than π radians. This means that it is possible to compensate for each discontinuity caused by the inverse tangent function periodicity and thus unwrap the argument function.

The average slope, α_k , of the linear part of the argument function can be calculated, as shown in equation (1), or by some other standard method, using the

unwrapped argument function of X_k for the k th frame

$$\alpha_k = \frac{1}{N} \sum_n \angle \frac{X_{n,k}}{n} \dots\dots\dots (1)$$

Where N is the number of active carriers and $X_{n,k}$ is the unwrapped argument function for the n th active carrier in the k th frame.

If the lowest frequency carriers are not present in the frame, it is not possible to find the true argument function, because there will be an unknown starting value for the available part of the function. This is not a problem in the present case, since the slope can still be calculated.

Equation (2) shows an algorithm that gives the average slope of a contiguous band of active carriers. Indices n_0 and n_2 are the lower and upper limits respectively of the band. Index n_1 divides the band into two equal parts. If several separate bands are used, equation (2) is applied to each band and the average of the results is calculated.

$$\alpha_k = \frac{2}{n_2 - n_0} \left[\sum_{n=n_1+1}^{n_2} \angle X_{n,k} - \sum_{n=n_0}^{n_1} \angle X_{n,k} \right] \dots\dots\dots (2)$$

The algorithm, according to equation (2), gives a very simple hardware implementation for OFDM receivers.

The unique novelty in the technique of the present invention resides in the separation of the inverse channel model into two parts, one of which is sample timing dependent and the other of which is sample timing independent.

If the sample timing and the equalizer are controlled by separate techniques they might counteract each others actions, because, both the equalizer and the sample timing influence time delay. This situation could eventually lead

to a drift of the frame timing out of the correct interval (the cyclically permuted signal interval). This cannot happen with the technique of the present invention.

The sample timing control, provided by the present invention, is very robust against external disturbance, because every active carrier is used in the timing deviation estimation.

CLAIMS

1. A receiver, for use in an OFDM type transmission system, in which data is transmitted in frames, each frame having a cyclic prefix which is a repetition of part of said frame, characterised in that control means are provided which control a sampling oscillator, and in that said control means include estimation means for estimating timing deviations of said sampling clock, said estimation means operating entirely on frequency domain input data.

2. A receiver, for use in an OFDM type transmission system, in which data is transmitted in frames, each frame having a cyclic prefix which is a repetition of part of said frame, and in which said receiver has an adaptive equaliser having an equaliser inverse channel model, characterised in that separation means are provided for separating said equaliser inverse channel model into a first and a second part, said first part being independent of sample timing and said second part being dependent on sample timing and in that control means are provided which control a sampling oscillator in dependence on said second part.

3. A receiver, as claimed in claim 2, characterised in that said control means include estimation means for estimating timing deviations of said sampling clock, said estimation means operating entirely on frequency domain input data.

4. A receiver, as claimed in claim 3, characterised in that said estimation means estimate an approximation of a linear portion of an argument function produced by timing deviations of said sampling oscillator.

5. A receiver, as claimed in claim 4, characterised in that said estimation means is adapted to find a linear part of said argument function by taking an average slope of said argument function.

6. A receiver, as claimed in either claim 4, or claim 5, characterised in that said approximation of a linear portion of an argument function is used as a feedback control signal for said sampling clock.

7. A receiver, as claimed in claim 6, characterised in that said approximation of a linear portion of an argument function has a slope which converges to zero as a control loop, for said sampling clock, settles.

8. A receiver, as claimed in claim 7, characterised in that those parts of said equaliser inverse channel model, other than said linear portion of said argument function, are controlled by said equaliser, which continuously adapts to variations in sampling timing.

9. A receiver, as claimed in claim 8, characterised in that said equaliser and said control means each use well defined and different portions of said equaliser inverse channel model to achieve an output frequency domain signal with zero phase deviation relative to a transmitted signal.

10. A receiver, as claimed in any of claims 7 to 9, characterised in that said slope of said argument function, α_k , is estimated from the equation

$$\alpha_k = \frac{1}{N} \sum_n \angle \frac{X_{n,k}}{n}$$

where N is the number of active carriers and $X_{n,k}$ is the unwrapped argument function for the nth active carrier in the kth frame.

11. A receiver, as claimed in any of claims 7 to 9, characterised in that said slope of said argument function, α_k , is estimated from the equation

$$\alpha_k = \frac{2}{n_2 - n_0} \left[\sum_{n=n_0+1}^{n_2} \angle X_{n,k} - \sum_{n=n_0}^{n_1} \angle X_{n,k} \right]$$

where N is the number of active carriers, $X_{n,k}$ is the unwrapped argument function for the nth active carrier in the kth frame, indices n_0 and n_2 are the lower and upper limits respectively of the band and index n_1 divides the band into two equal parts.

12. A receiver, as claimed in any previous claim, characterised in that, on start up, frame timing is adjusted until received frames are sampled inside a signal interval.

13. A receiver, as claimed in claim 12, characterised in that means are provided, responsive to a feed back control for said sampling oscillator, to adjust said frame timing so that frame synchronization is maintained.

14. An OFDM type transmission system in which data is transmitted in frames, each frame having a cyclic prefix which is a repetition of part of said frame, characterised in that said system includes a receiver as claimed in any of claims 1 to 13.

15. In an OFDM type system in which data is transmitted in frames, each frame having a cyclic prefix which is a repetition of part of said frame, a method of synchronising a receiver sampling oscillator with a transmitter sampling oscillator, characterised by controlling said sampling oscillator with a feedback signal representing an estimation of timing deviations of said sampling clock, said estimation signal derived directly from domain input data.

16. In an OFDM type system in which data is transmitted in frames, each frame having a cyclic prefix which is a repetition of part of said frame, and in which said receiver has an adaptive equaliser having an equaliser inverse channel model, a method of synchronising a receiver sampling oscillator with a transmitter sampling oscillator, characterised by separating said equaliser inverse channel model into a first and a second part, said first part being independent of sample timing and said second part being dependent on sample timing and controlling a sampling oscillator in dependence on said second part.

17. A method, as claimed in claim 16, characterised by estimating timing deviations of said sampling clock entirely from frequency domain input data.

18. A method, as claimed in claim 17, characterised by estimating an approximation of a linear portion of an argument function produced by timing

deviations of said sampling oscillator.

19. A method, as claimed in claim 18, characterised by finding a linear part of said argument function by taking an average slope of said argument function.

20. A method, as claimed in either claim 18, or claim 19, characterised by using said approximation of a linear portion of an argument function as a feedback control signal for said sampling clock.

21. A method, as claimed in claim 20, characterised by said approximation of a linear portion of an argument function having a slope which converges to zero as a control loop, for said sampling clock, settles.

22. A method, as claimed in claim 21, characterised by controlling those parts of said equaliser inverse channel model, other than said linear portion of said argument function, with said equaliser, which continuously adapts to variations in sampling timing.

23. A method, as claimed in claim 22, characterised by said equaliser and said control means each using well defined and different portions of said equaliser inverse channel model to achieve an output frequency domain signal with zero phase deviation relative to a transmitted signal.

24. A method, as claimed in any of claims 21 to 23, characterised by estimating said slope of said argument function, α_k , from the equation

$$\alpha_k = \frac{1}{N} \sum_n \angle \frac{X_{n,k}}{n}$$

where N is the number of active carriers and $X_{n,k}$ is the unwrapped argument function for the nth active carrier in the kth frame.

25. A method, as claimed in any of claims 21 to 23, characterised by estimating said slope of said argument function, α_k , from the equation

$$\alpha_k = \frac{2}{n_2 - n_0} \left[\sum_{n=n_1+1}^{n_2} \angle X_{n,k} - \sum_{n=n_0}^{n_1} \angle X_{n,k} \right]$$

where N is the number of active carriers, $X_{n,k}$ is the unwrapped argument function for the nth active carrier in the kth frame, indices n_0 and n_2 are the lower and upper limits respectively of the band and index n_1 divides the band into two equal parts.

26. A method, as claimed in any of claims 15 to 25, characterised by adjusting frame timing, on start, until received frames are sampled inside a signal interval.

27. A method, as claimed in claim 26, characterised by adjusting said frame timing in accordance with a feed back signal for said sampling oscillator, so that frame synchronization is maintained.

28. An ADSL modem characterised in that said modem has a receiver as claimed in any of claims 1 to 13, or operates a method of synchronisation as claimed in any of claims 15 to 27

29. A VDSL modem characterised in that said modem has a receiver as claimed in any of claims 1 to 13, or operates a method of synchronisation as claimed in any of claims 15 to 27.

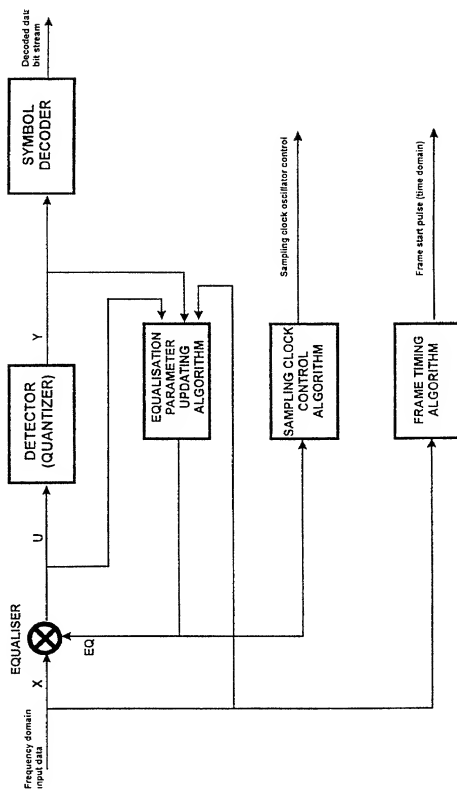
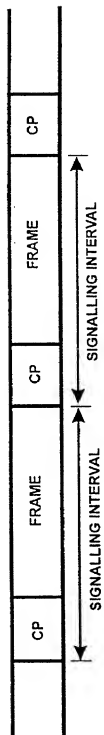


Figure 2



CP = CYCLIC PREFIX

Figure 2

Declaration, Power Of Attorney and Petition

Page 1 of 6

WE (I) the undersigned inventor(s), hereby declare(s) that:

My residence, post office address and citizenship are as stated below next to my name,

We (I) believe that we are (I am) the original, first, and joint (sole) inventor(s) of the subject matter which is claimed and for which a patent is sought on the invention entitled

IMPROVEMENTS IN, OR RELATING TO SYNCHRONISATION

the specification of which

☐ is attached hereto.

☒ was filed on 03 November 1998 as

Application Serial No. 09/147,230

and amended on

☒ was filed as PCT international application

Number PCT/SE98/00353

on 27 February 1998,

and was amended under PCT Article 19

on (if applicable).

We (I) hereby state that we (I) have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

We (I) acknowledge the duty to disclose information known to be material to the patentability of this application as defined in Section 1.56 of Title 37 Code of Federal Regulations.

We (I) hereby claim foreign priority benefits under 35 U.S.C. § 119(a)-(d) or § 365(b) of any foreign application(s) for patent or inventor's certificate, or § 365(a) of any PCT International application which designated at least one country other than the United States, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate, or PCT International application having a filing date before that of the application on which priority is claimed. Prior Foreign Application(s)

Application No.	Country	Day/Month/Year	Priority Claimed
9700784-3	SWEDEN	3 March 1997	<input checked="" type="checkbox"/> Yes <input type="checkbox"/> No
9703629-7	SWEDEN	6 October 1997	<input checked="" type="checkbox"/> Yes <input type="checkbox"/> No
			<input type="checkbox"/> Yes <input type="checkbox"/> No
			<input type="checkbox"/> Yes <input type="checkbox"/> No

We (I) hereby claim the benefit under Title 35, United States Code, § 119(e) of any United States provisional application(s) listed below.

_____	_____
(Application Number)	(Filing Date)
_____	_____
(Application Number)	(Filing Date)

We (I) hereby claim the benefit under 35 U.S.C. § 120 of any United States application(s), or § 365(c) of any PCT International application designating the United States, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT International application in the manner provided by the first paragraph of 35 U.S.C. § 112, I acknowledge the duty to disclose information which is material to patentability as defined in 37 CFR § 1.56 which became available between the filing date of the prior application and the national or PCT International filing date of this application.

Application Serial No.	Filing Date	Status (pending, patented, abandoned)
PCT/SE98/00353	27 February 1998	_____
_____	_____	_____
_____	_____	_____

And we (I) hereby appoint: Norman F. Oblon, Registration Number 24,618; Marvin J. Spivak, Registration Number 24,943; C. Irvin McClelland, Registration Number 21,124; Gregory J. Maier, Registration Number 25,529; Arthur I. Neustadt, Registration Number 24,854; Richard D. Kelly, Registration Number 27,757; James D. Hamilton, Registration Number 28,421; Eckhard H. Kuesters, Registration Number 28,870; Robert T. Pous, Registration Number 29,099; Charles L. Gholz, Registration Number 26,395; Vincent J. Sunderdick, Registration Number 29,004; William E. Beaumont, Registration Number 30,996; Steven B. Kalber, Registration Number 30,073; Robert F. Gnuse, Registration Number 27,295; Jean-Paul Lavalleye, Registration Number 31,451; Stephen G. Baxter, Registration Number 32,884; Martin M. Zoltick, Registration Number 35,745; Robert W. Hahl, Registration Number 33,893; Richard L. Treanor, Registration Number 36,379; Steven P. Weihrouch, Registration Number 32,829; John T. Goolkasian, Registration Number 26,142; Marc R. Labgold, Registration Number 34,654; William J. Healey, Registration Number 36,160; Richard L. Chinn, Registration Number 34,305; Steven E. Lipman, Registration Number 30,011; Carl E. Schlier, Registration Number 34,426; James J. Kulbaski, Registration Number 34,648; Catherine B. Richardson, Registration Number 39,007; Richard A. Neifeld, Registration Number 35,292; J. Derek Mason, Registration Number 35,270; and Surinder Sachar 34,423; our (my) attorneys, with full powers of substitution and revocation, to prosecute this application and to transact all business in the Patent Office connected therewith; and we (I) hereby request that all correspondence regarding this application be sent to the firm of OBLON, SPIVAK, MCCLELLAND, MAIER & NEUSTADT, P.C., whose Post Office Address is: Fourth Floor, 1755 Jefferson Davis Highway, Arlington, Virginia 22202.

We (I) declare that all statements made herein of our (my) own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

Lennart OLSSON
NAME OF FIRST SOLE INVENTOR

Residence: Malvagen 39, S-973 31 Lulea,
SWEDEN

Lennart Olsson
Signature of Inventor

Citizen of: SWEDEN

Post Office Address: same as above

9 December 1998
Date

2.00
Gunnar BAHLENBERG

NAME OF SECOND JOINT INVENTOR

Gunnar Bählenberg
Signature of Inventor

1998-12-10
Date

3.00
Daniel RENGSSON

NAME OF THIRD JOINT INVENTOR

Daniel Rengsson
Signature of Inventor

1998-12-10
Date

4.00
Siwert HÅKANSSON

NAME OF FOURTH JOINT INVENTOR

Siwert Håkansson
Signature of Inventor

✓ 98-12-18
Date

5.00
Anders ISAKSSON

NAME OF FIFTH JOINT INVENTOR

Anders Isaksson
Signature of Inventor

1998-12-10
Date

Residence: Blidvagen 234, S-976 32 Lulea,

SWEDEN

Citizen of: SWEDEN *SEX*

Post Office Address: same as above

Residence: Forskarvagen 36 A, S-977

53 Lulea, SWEDEN *JEV*

Citizen of: SWEDEN

Post Office Address: same as above

Residence: Aprilvägen 10, S-177 61

Järfälla, SWEDEN *JEV*

Citizen of: SWEDEN

Post Office Address: same as above

Residence: Elevvagen 1, S-977 25 Lulea,

SWEDEN *JEV*

Citizen of: SWEDEN

Post Office Address: same as above

Lars-Ake ISAKSSON
NAME OF SIXTH JOINT INVENTOR

Lars-Ake Isaksson
Signature of Inventor

981210
Date

Mikaal ISAKSSON
NAME OF SEVENTH JOINT INVENTOR

Mikaal Isaksson
Signature of Inventor

981209
Date

Magnus JOHANSSON
NAME OF EIGHTH JOINT INVENTOR

Magnus Johansson
Signature of Inventor

1998-12-10
Date

Mauritz LAHTI
NAME OF NINTH JOINT INVENTOR

Mauritz Lahti
Signature of Inventor

1998-12-11
Date

Residence: Residensgatan 6 C, S-972 36
Lulea, SWEDEN

Citizen of: SWEDEN *SE*

Post Office Address: same as above

Residence: Borgmastarevagen 7, S-973
42 Lulea, SWEDEN

Citizen of: SWEDEN *SE*

Post Office Address: same as above

Residence: Timmermansgatan 34, S-972
41 Lulea, SWEDEN

Citizen of: SWEDEN *SE*

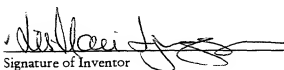
Post Office Address: same as above

Residence: Lingonstigen 63, 3tr,
S-973 33 Lulea, SWEDEN

Citizen of: SWEDEN *SE*

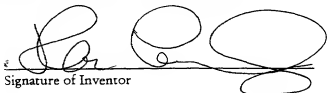
Post Office Address: same as above

10-60
Lis-Marie LUNGGREN
NAME OF TENTH JOINT INVENTOR


Signature of Inventor

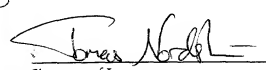
14 Dec 1998
Date

Hans LUNDBERG
NAME ELEVENTH JOINT INVENTOR

11-60

Signature of Inventor


14 Dec 1998
Date

12-60
Tomas NORDSTROM
NAME TWELFTH JOINT INVENTOR


Signature of Inventor

14 Dec 1998
Date

17-00
Sven-Rune OLOFSSON
NAME THIRTEENTH JOINT INVENTOR


Signature of Inventor

11 Dec 1998
Date

Residence: Praktikantvagen 31, S-977
53 Lulea, SWEDEN

SEX
Citizen of: SWEDEN

Post Office Address: same as above

Residence: Vastra Solgatan 8, S-972 53
Lulea, SWEDEN

SEX
Citizen of: SWEDEN

Post Office Address: same as above

Residence: Docentvagen 279, S-955 52
Lulea, SWEDEN

SEX
Citizen of: SWEDEN

Post Office Address: same as above

Residence: Malmuddsvagen 9, S-972 45
Lulea, SWEDEN

SEX
Citizen of: SWEDEN

Post Office Address: same as above

Tomas STEFANSSON
NAME OF FOURTEENTH JOINT INVENTOR

14-00
Tomas SH
Signature of Inventor

10 dec 1998
Date

Hans OMAN
NAME OF FIFTEENTH JOINT INVENTOR

15-60
Hans Oman
Signature of Inventor

11 dec 1998
Date

Goran OKVIST
NAME OF SIXTEENTH JOINT INVENTOR

16-60
G-82
Signature of Inventor

10 December 1998
Date

NAME OF SEVENTEENTH JOINT INVENTOR

Signature of Inventor

Date

Residence: Lulavan 773, S-961 93 Boden,
SWEDEN

Citizen of: SWEDEN

Post Office Address: same as above

Residence: Faltspatstigen 21, S-977 53
Lulea, SWEDEN

Citizen of: SWEDEN

Post Office Address: same as above

Residence: Hagaplan 7, S-974 41 Lulea,
SWEDEN

Citizen of: SWEDEN

Post Office Address: same as above

Residence: _____

Citizen of: _____

Post Office Address: _____